THREE DIMENSIONAL OPTICAL SWITCHES AND BEAM STEERING MODULES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 09/536,164 to Michael J. Daneman, Berhang Behin, and Satinderpall S. Pannu, filed Mar. 25, 2000 now U.S. Pat. No. 6,330,102 and entitled "Apparatus and method for 2-Dimensional Steered-Beam N×M Optical Switch Using Single-Axis Mirror Arrays and Relay Optics", which is incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates generally to fiber optic communications. More particularly, the invention relates to optical routing.

BACKGROUND ART

Modern fiber optical communications systems direct optical signals over multiple fibers. Such systems require optical switches to direct light beams from any given fiber in an input fiber array to any given fiber in an output array. One class of optical switches uses an approach called beam steering. In beam steering, the light from the fiber is selectively deflected or steered by one or more movable optical element from the input fiber to the output fiber. Suitable optical elements include microelectromechanical system (MEMS) mirrors. MEMS mirrors are usually actuated by magnetic interaction, electrostatic, or piezoelectric interaction. Typically, two sets of moveable mirrors are used to steer the beam. Each fiber has a small "acceptance window". The fiber only efficiently couples light that is incident within a narrow range of angles and positions. Although a single mirror will generally direct the beam from an input fiber to the correct output fiber, two mirrors ensure that the light beam enters the output fiber at the correct angle. If the beam makes too large an angle with the axis of the fiber, light from the beam will not couple properly to the fiber, i.e. there will be high losses.

Optical switches using the steering-beam approach have been demonstrated in two primary implementations. The first uses linear arrays of mirrors with a single angular degree of freedom. Combining two such mirror arrays as shown in FIG. **1** allows an implementation of an N×N optical switch, where the number of input and output channels is equal to the number of mirrors in each array. The first array steers an optical beam from an input fiber to the appropriate mirror on the second array, which then steers the beam into the corresponding output fiber. This implementation uses simple single-axis mirrors; however, it is limited in its scalability since the optical path between fibers becomes unreasonably large for large port counts (e.g. >32×32), increasing the loss of the switch.

The second implementation depicted in FIG. **2** uses two sets of 2-dimensional mirror arrays, each mirror having two angular degrees of freedom. The input and output fibers are each also arranged in a 2-dimensional grid with the same dimension as the mirror arrays. The mirrors in the first mirror array steer the optical beams from the fibers onto the appropriate mirror in the second mirror array which then steers the beam into the corresponding fiber. This approach is considerably more scalable, since, due to its 2-dimensional layout, the size of the mirror and fiber arrays

grows as the square root of the number of input/output ports, which is much slower than in the case of a 1-dimensional grid. Therefore, switches with much larger port count (>2000×2000) are possible. However, this implementation requires the mirrors to rotate about two different axes. Such mirrors are considerably more difficult to design, fabricate, and control.

Prior art beam steering approaches as shown in FIG. **1** typically deflect light ~90 degrees to another deflector which deflects the light at an offset of 90 degrees such that input and output fiber arrays are substantially parallel. Such beam steering optical switches deflect photons from an input to the output mirror array where the deflected light from the input mirror array causes the beam to be substantially perpendicular to the input fiber array. These designs are not modular, are limited in the number of ports they can physically occupy, and are subject to a fixed geometry.

Another disadvantage of existing optical switches is that they tend to be monolithic in design, i.e., the mirror arrays are fixed components of the switch that are neither removable nor interchangeable. As a result, a prior art switch cannot easily be reconfigured or repaired.

There is a need, therefore, for a beam steering apparatus that overcomes the above disadvantages.

SUMMARY

These disadvantages associated with the prior art may be overcome by a beam steering module. The steering module generally comprises first and second N×M arrays of single axis mirrors. The mirrors in the first array rotate about a particular axis while the mirrors in the second array rotate about an axis different from the first axis (. Relay optics may be disposed between the two arrays image the first mirror array onto the second mirror array such that the beam angle may be controlled with respect to both axes by adjusting the angle of the appropriate mirrors in the first and second mirror grids.

Two steering modules may be combined to form a beam steering system. With two modules, it is possible to completely determine, at the plane of the output fiber grid, the position and angle of an optical beam emerging from any of the input fibers.

Embodiments of the steering modules of the present invention may be used to selectively couple light from an input fiber in an N×N input fiber module array to any output fiber in an M×M output fiber module array, or from an input fiber to an output fiber in an N×N module array. The beam steering modules of the present invention may be used interchangeably to achieve full-duplex operation modules functioning as inputs and outputs.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** depicts a one-dimensional beam steering apparatus according to the prior art;

FIG. **2** depicts an isometric view of a two-dimensional beam steering apparatus according to the prior art;

FIG. **3** depicts a beam steering module according to a first embodiment of the present invention;

FIGS. **4** depicts an isometric view of a beam steering apparatus according to a second embodiment of the present invention;

FIG. **5** depicts a schematic diagram depicting a modular optical switch according to a first alternative version of a third embodiment of the invention;

FIGS. **6**A–**6**B depicts a modular optical switch according to a second alternative version of the third embodiment of the invention;